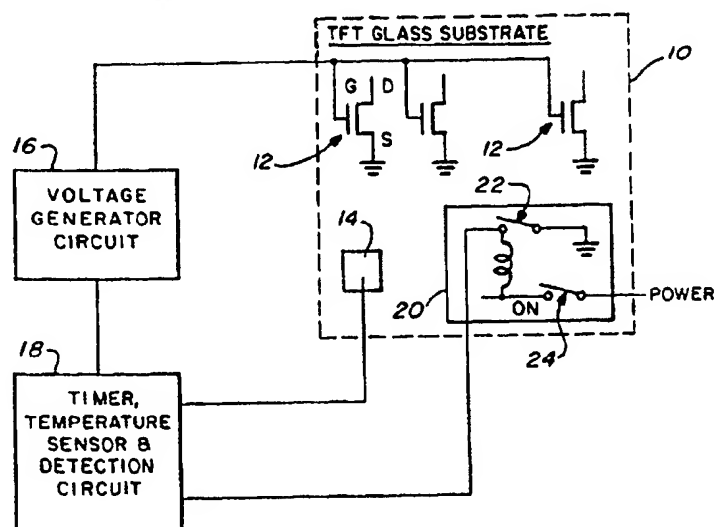




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(54) Title: APPARATUS FOR RECOVERY OF THRESHOLD VOLTAGE SHIFT IN AMORPHOUS SILICON THIN-FILM TRANSISTOR DEVICE



## (57) Abstract

An apparatus is provided for recovery of a threshold voltage,  $V_{th}$ , of thin-film amorphous silicon transistors (12) deposited on a substrate (10) and a gate voltage is applied to each of the transistors (12) during use, causing  $V_{th}$  to shift with time. The apparatus detect when the LCD display (10) is not being used, generates a voltage  $V_g'$ , of opposite polarity with respect to  $V_g$  when the LCD display is not being used, and applies  $V_g'$  to the gates of the transistors (12) of the LCD display (10) for causing  $V_{th}$  to shift in a direction opposite to that caused by  $V_g$ , thereby maintaining an effective driving voltage for the transistor (12) of the LCD display (10).

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APPARATUS FOR RECOVERY OF THRESHOLD VOLTAGE SHIFT IN AMORPHOUS SILICON THIN-FILM TRANSISTOR DEVICE.

The present invention relates generally to a threshold  
5 voltage shift recovery apparatus associated with amorphous  
silicon (a-Si:H) thin-film transistor (TFT) devices. More  
particularly the invention is directed towards a-Si:H TFT  
devices used in an LCD display such as data driver and scan  
driver circuits or in pixel switching elements.

10 Amorphous silicon TFT's have been widely used in  
active matrix LCD displays because of their good switching  
characteristics. However, the threshold voltage,  $V_{th}$ ,  
shifting during operation shows instability of the  
amorphous silicon and hence factors such as temperature and  
15 applied voltage can cause its character to change during  
use of the LCD display. Studies have shown that the time  
dependence of this threshold voltage shift is due to gate  
bias voltage. Threshold voltage shift is accelerated when  
the devices are operated under increasingly higher  
20 temperature conditions.

Threshold voltage,  $V_{th}$ , can be defined, when plotted  
in graphic form, as the voltage,  $V_g$ , of the gate of a TFT  
along an abscissa intersected by a plot of the square root  
of the TFT drain current,  $I_{ds}$  along the ordinate axis. In  
25 LCD display operations a gate voltage,  $V_g$ , that is greater  
than the  $V_{th}$  is necessary to give enough current to drive  
the TFT pixel elements of the LCD display. The shifting of  
 $V_{th}$  over time, and accelerated with increased temperature,  
reduces the effective driving voltage between the gate and  
30 source and also reduces the source drain current,  $I_{ds}$ ,  
which results in the degrading of the LCD TFT display  
performance.

Therefore, it is very important and desirable to  
maintain the threshold value,  $V_{th}$ , during the lifetime of  
35 the LCD display since the shifting of  $V_{th}$  results in the  
inability of  $V_g$  to properly open or close the pixel TFTs.

For example, within the amorphous silicon TFT, a threshold voltage shift of 6-to-7 volts may occur when a positive 40 volts DC is applied to the TFT gate for approximately 15 hours at 25°C, as shown in FIG. 1. A  $V_{th}$  shift of approximately 5 volts may occur when a 30 volt AC pulse with a 50% duty cycle is applied to the TFT gate for approximately 88 hours, as shown in FIG. 2. The direction of the threshold voltage shift depends on the sign of the voltage between the gate and source of a given TFT. A negative threshold voltage shifting occurs when a negative DC voltage is applied to the TFT gate for a period of time. For example, in FIG. 1, an approximately negative 2.3 voltage shift of  $V_{th}$  is shown when a negative 20 volts is applied to a TFT gate.

The equation commonly used to describe the  $V_{th}$  shift,  $\Delta V_{th}$ , can be expressed as:

$$\Delta V_{th} = A \exp(-E_a/kT) (\log t)^\alpha V_g^\beta,$$

where A is a constant, k is the Boltzmann constant, T is the absolute temperature of the TFT and t is the amount of time a bias  $V_g$  has been applied to the gate of the TFT. The values of activation energy,  $E_a$ , and parameters  $\alpha$  and  $\beta$  are best obtained through experimentation through the well-known method of least square fitting, because the parameters depend on the properties of the amorphous silicon sample and the insulator used in the display.

The above equation clearly shows the dependence of  $V_{th}$  on temperature, time, and gate voltage. One of the theories to explain this phenomenon is to attribute the  $\Delta V_{th}$  to charge trapping in the nitride. Another theory is the creation of meta-stable Si-dangling bonds in the accumulation layer of the amorphous silicon film.

A voltage shift of about 4 volts has been observed in a TFT-LCD after approximately 10,000 hours of operation at 80°C. In general, to maintain a sufficient driving current, a  $\Delta V_{th}$  of less than 2 volts is required during the

lifetime of the display. In critical applications such as projection TV, the TFTs are under constant high temperature and the  $\Delta V_{th}$  will be more pronounced in a shorter period of time. Other applications in which a significant  $\Delta V_{th}$  will be achieved include aviation and automobile applications.

In TFT-LCD display operations a high gate voltage,  $V_g$ , is necessary to produce enough current to drive the pixel or other elements of the display due to the low mobility of the a-Si TFTs. The shifting of  $V_{th}$  reduces the effective driving voltage between the gate and source and thereby reduces the source drain current,  $I_{ds}$ , resulting in a degradation of performance. Therefore, it is highly desirable to maintain a low  $V_{th}$  during the lifetime of the display.

There are several known methods for reducing and/or slowing down the shifting of the threshold voltage,  $V_{th}$ . One known method uses high temperature annealing to slow down the threshold voltage shifting by, for example, baking an LCD display in a high temperature oven for a fixed period of time. However, it is impractical and expensive to anneal a TFT-LCD display after it has been assembled.

Another method to control  $\Delta V_{th}$  is to reduce the applied gate voltage,  $V_g$ , since  $\Delta V_{th}$  is proportional to  $V_g$ . However, a high gate voltage is necessary to produce enough current to drive other elements due to the low mobility of the amorphous silicon TFTs. Therefore, a lower gate voltage results in a significant reduction in the performance of the LCD display.

The third method uses a negative biased voltage to "drive back" a positive shifting  $V_{th}$ . This method utilizes applying a gate voltage to a scan line of TFT's while the line is not activated. This method requires complicated analysis in order to minimize the shift of  $V_{th}$  because there are practical limits to the magnitude and duration of the applied negative gate voltage. This is because, for each frame, each scan line has to turn ON within 1/60 of a

second. This makes the required circuitry very complex in order to have the  $V_{th}$  shifted properly.

It is, therefore, an object of the present invention to provide an apparatus for an improved recovery of the threshold voltage shifting of an amorphous silicon TFT-LCD display.

It is a further object of the present invention to provide a simple and easily implemented apparatus to reduce the shifting of the threshold voltage.

It is a still further object of the present invention to provide an apparatus for recovering the threshold voltage shift while the TFT-LCD display is OFF and not being used.

The present invention provides an apparatus for recovering a threshold voltage,  $V_{th}$ , of thin-film amorphous silicon transistors deposited on a substrate of a display and a gate voltage,  $V_g$ , is applied to each of the transistors during use causing  $V_{th}$  to increase with time, the apparatus comprising:

detection means operably coupled to the display for detecting when the display is not in use; and,

voltage generation means operably coupled to said detection means for generating a voltage,  $V_g'$ , of opposite polarity with respect to  $V_g$  when the display is not in use, and wherein,

said voltage,  $V_g'$ , is applied to the gates of the transistors of the display only when it is not in use for causing  $V_{th}$  to decrease with time thereby maintaining an effective driving voltage for the transaction of the display. An effective driving voltage for the pixel elements of the LCD display is thereby maintained.

These and other objects of the present invention will be more clearly understood in connection with the accompanying drawings in which:

Fig. 1 is a graph of the threshold voltage shift of a TFT relative to an applied gate voltage;

FIG. 2 is a graph of the threshold voltage shift of a TFT after 88 hours of operation;

FIG. 3 is a graph of the threshold voltage recovery of a TFT after a negative 20 volts has been applied for 16 hours; and

FIG. 4 is a block diagram of an apparatus for controlling the  $V_{th}$  in accordance with the present invention.

In FIG. 2 a typical threshold voltage shift is shown for an amorphous silicon transistor after approximately 88 hours of 30 VAC being applied to the gate. As can be seen in FIG. 2,  $V_{th}$  has shifted approximately 5 volts during this 88 hours of use.

FIG. 3 is a graph of the threshold voltage recovery provided by the present invention. FIG. 3 illustrates the recovery of  $V_{th}$  to within approximately 0.9 volts of the initial  $V_{th}$  after a negative 20 volts was applied to the TFT gates for approximately 16 hours during the time the TFT-LCD display was turned OFF. The threshold voltage can be fully recovered to the original  $V_{th}$  if a longer time and/or a higher negative voltage is applied to the gates.

The magnitude of the negative DC voltage and the time duration of this negative voltage applied to the gate of the TFT device can be designed according to the display application.

FIG. 4 discloses a block diagram of a recovery circuit of the invention. A TFT glass substrate 10 is shown with thin-film transistors 12 deposited thereon. A temperature sensor 14, which is preferably a thermocouple, diode or resistive sensor, is shown within substrate 10 and can be deposited either directly on substrate 10 or attached within the display such that the sensor is adjacent to substrate 10. A voltage generator circuit 16 is connected to the gates of TFTs 12. A timer, temperature sensor and detection circuit 18 is connected to temperature sensor 14 and voltage generator circuit 16 for controlling the operation of circuit 16.

A circuit 20 is provided for indicating to detection circuit 18 when TFTs 12 are being used. Circuit 20 includes a normally open relay 22 and an ON/OFF switch 24. When switch 24 is turned ON, this causes normally open  
5 relay 22 to close, thereby enabling detection circuit 18 to activate a timer to begin measuring the use of the LCD display. Also, detection circuit 18 senses when relay 22 is open. Circuit 18 then enables circuit 16 to apply a voltage,  $V_g$ , to the gates of TFTs 12 only when it senses  
10 that the LCD display is in the OFF state so as to cause  $V_{th}$  to shift in a direction opposite of that caused by  $V_g$  during the time the LCD display is in the ON state.

During use of the invention, the voltage,  $V_g'$ , applied to the gates of the amorphous silicon transistors 12 can be  
15 simply applied for a fixed period of time and at a fixed magnitude to constantly offset the voltage threshold shift whenever the LCD is in the OFF state.

The novel method of the present invention requires the steps of detecting when the LCD display is in the OFF state  
20 and applying a negative voltage to the gates of the TFT transistors only during their OFF state to recover the threshold voltage shift that occurred during the ON state of the LCD display. The method also includes the step of applying a constant value negative voltage to the gates of  
25 the TFT transistors during the OFF state of the LCD display for a predetermined period of time.

In an alternate embodiment, the method further includes the step of applying a negative voltage to the  
30 gates of the TFT transistors for a period of time according to the equation

$$\Delta V_{th} = A \exp(-E_a/kT) (\log t)^{\alpha} V^{\beta}.$$

Thus, there has been disclosed a novel method and  
35 apparatus relating to the threshold voltage shift recovery that is associated with amorphous silicon TFT devices. Particularly when the devices are used in the LCD display

in the data driver and the scan driver circuits or in the pixel switching elements. The novel method and apparatus uses a self-generated negative voltage signal in the LCD display units and applies the negative voltage signal to the gate of an amorphous silicon TFT only when the LCD display is turned OFF or is not being used. This method and apparatus will recover the threshold shift of the devices and thus enhance the operation and prolong the useful life of the display.

10        However, in a more sophisticated application, the appropriate voltage and the needed time of application of the voltage to the LCD display in its OFF state can be calculated by circuit 18 which includes the temperature of substrate 10 in order to more accurately calculate the  
15        required magnitude and time duration of the voltage  $V_g'$ , to be applied to transistors 12. Such calculations may be necessary in an application such as HD-TV projection where the TFT's are exposed to relatively high temperatures.

CLAIMS

1. An apparatus for recovering a threshold voltage,  $V_{th}$ , of thin-film amorphous silicon transistors (12) deposited on a substrate (10) of a display and a gate voltage,  $V_g$ , is applied to each of the transistors during use causing  $V_{th}$  to increase with time, the apparatus comprising:

detection means (18) operably coupled to the display for detecting when the display is not in use; and, voltage generation means (16) operably coupled to the detection means for generating a voltage,  $V_g'$ , of opposite polarity with respect to  $V_g$  when the display is not in use, wherein,

the voltage,  $V_g'$ , is applied to the gates of the transistors of the display only when it is not in use for causing  $V_{th}$  to decrease with time thereby maintaining an effective driving voltage for the transaction of the display.

2. An apparatus according to claim 1, wherein:

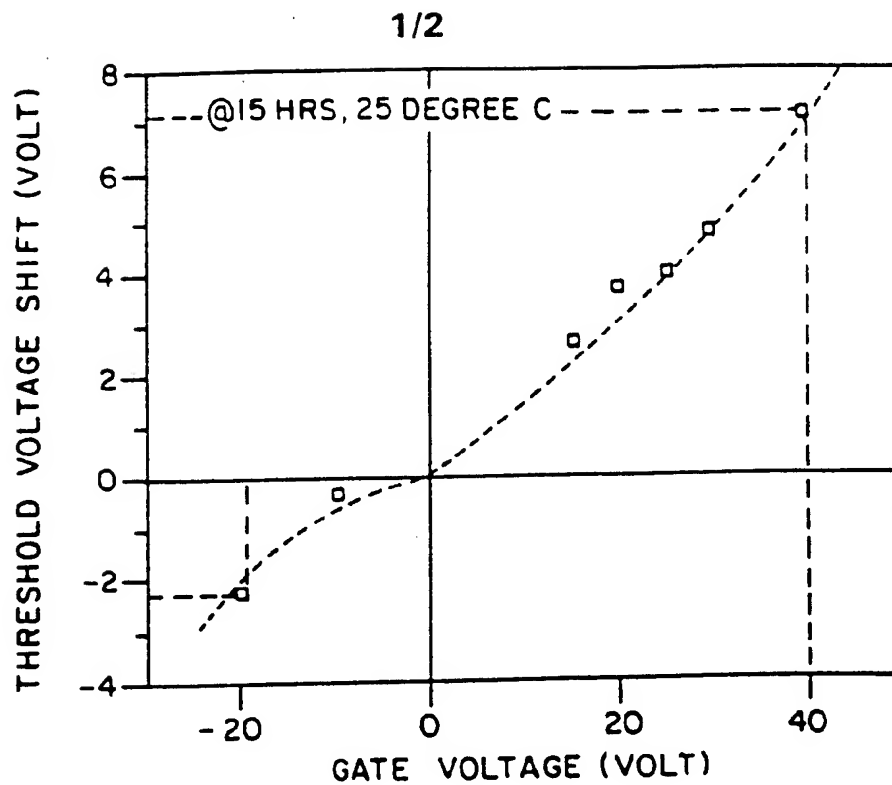
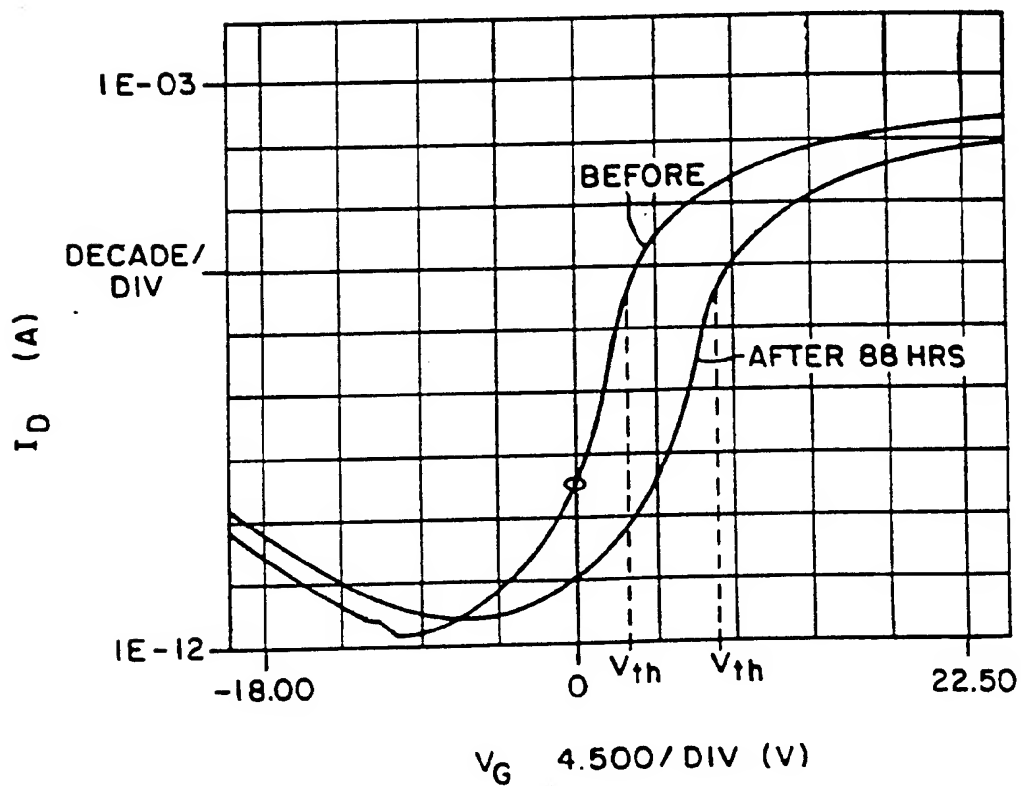
the detection means (16) includes means for detecting the amount of time the display (10) is in use; and the voltage,  $V_g'$ , is applied to the transistor gates (12) only when the display is not in use for an amount of time and at a magnitude proportional to the amount of time the display was in use.

3. An apparatus according to claim 2, wherein:

the detection means (16) includes means for detecting the temperature of the display (10) during its time of use; and

the voltage,  $V_g'$ , is applied for an amount of time and at a magnitude proportional to the temperature of the display during its time of use.

4. An apparatus according to claim 3, wherein the temperature detection means (16) includes a temperature sensor (14) deposited on the display substrate (10).
- 5 5. An apparatus according to claim 3, wherein the temperature detection means (16) includes a temperature sensor adjacent the display substrate.
- 10 6. An apparatus according to claim 5, wherein the temperature sensor (14) is one taken from the group consisting of thermocouple, diode and resistance sensors.
7. An apparatus according to claim 1, wherein the voltage generation (18) means includes a battery power supply.
- 15 8. An apparatus according to any one of the preceding claims, wherein the display (10) is an LCD.

**FIG. 1****FIG. 2**

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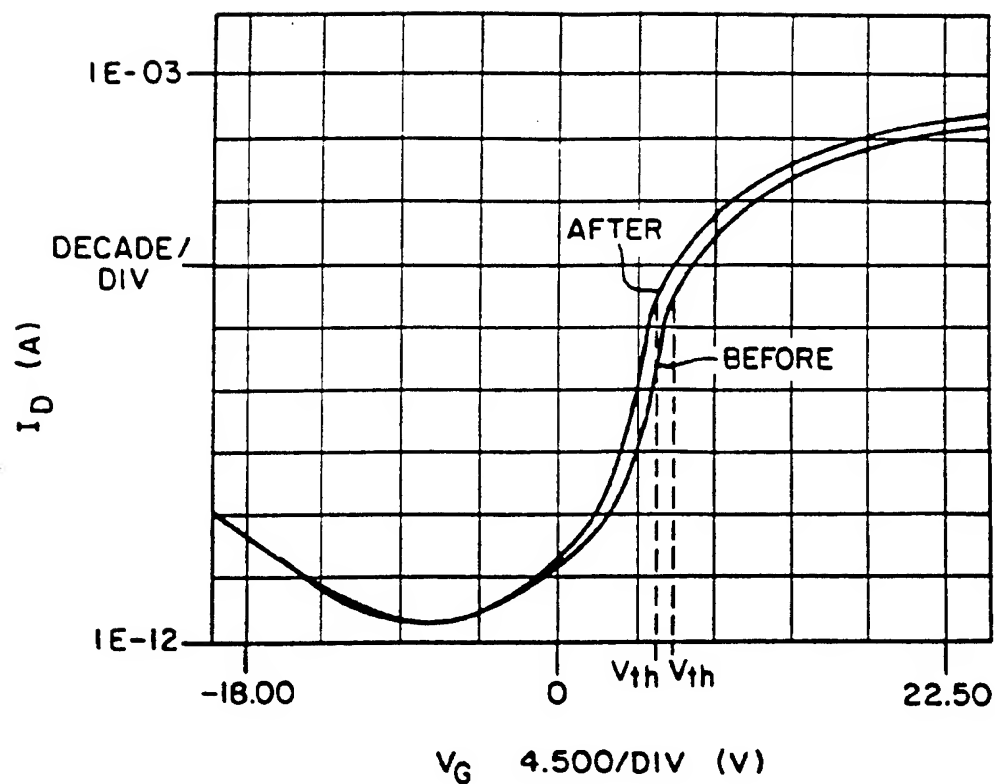


FIG. 3

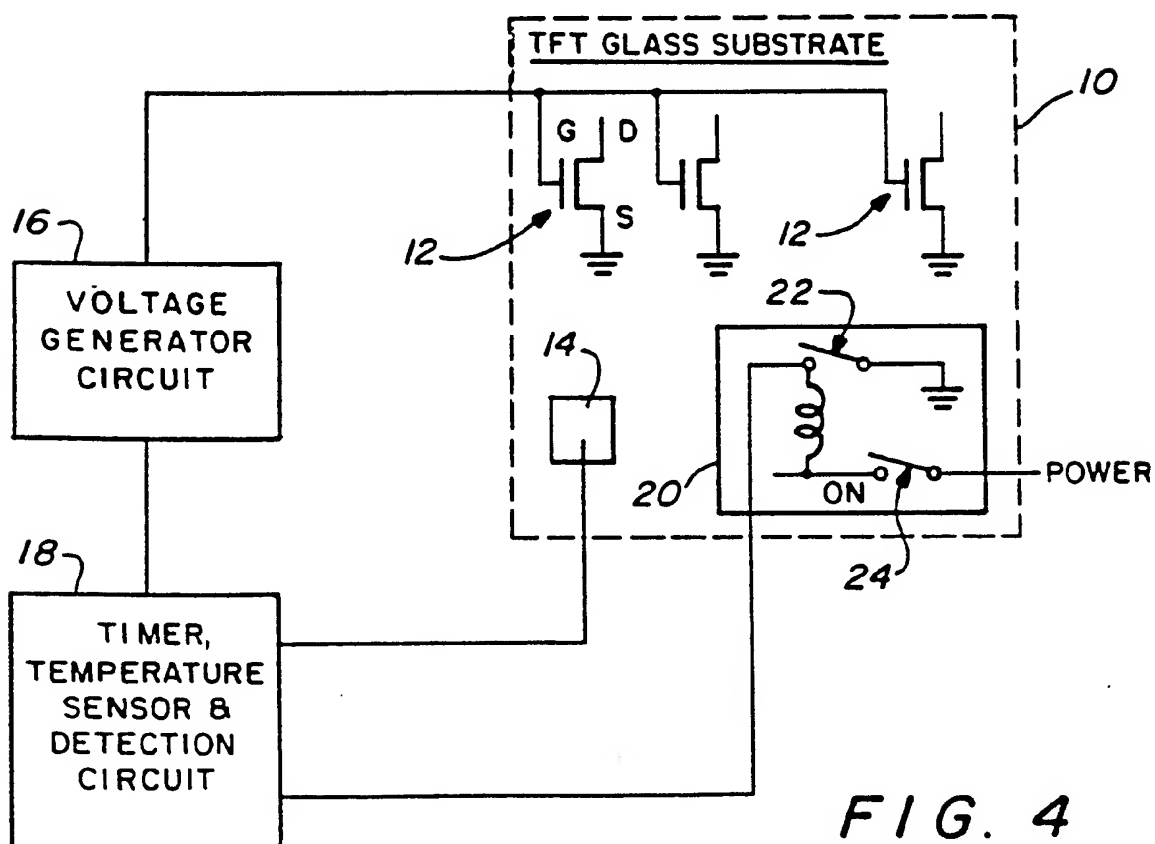


FIG. 4

## INTERNATIONAL SEARCH REPORT

International Application No

P /GB 94/00467

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 5 G09G3/36

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 5 G09G G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages   | Relevant to claim No. |
|------------|--|-----------------------|
| A          | IBM JOURNAL OF RESEARCH AND DEVELOPMENT<br>vol. 36, no. 1, January 1992, NEW YORK<br>US<br>pages 76 - 82<br>Y.FUJIMOTO 'Study of the Vth shift of the<br>thin-film transistor by the bias<br>temperature stress test'<br>see page 76, left column, line 1 - page<br>77, left column, line 9<br>--- | 1                     |
| A          | US,A,4 319 237 (MATSUO ET AL.) 9 March<br>1982<br>* Abstract *<br>see column 3, line 15 - line 55; figures<br>1,5,6,12<br>-----  | 1,3,6,8               |

☐ Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search

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# INTERNATIONAL SEARCH REPORT

Inter nal Application No

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| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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